Air Capture of Carbon Dioxide

Closing the Fuel Cycle

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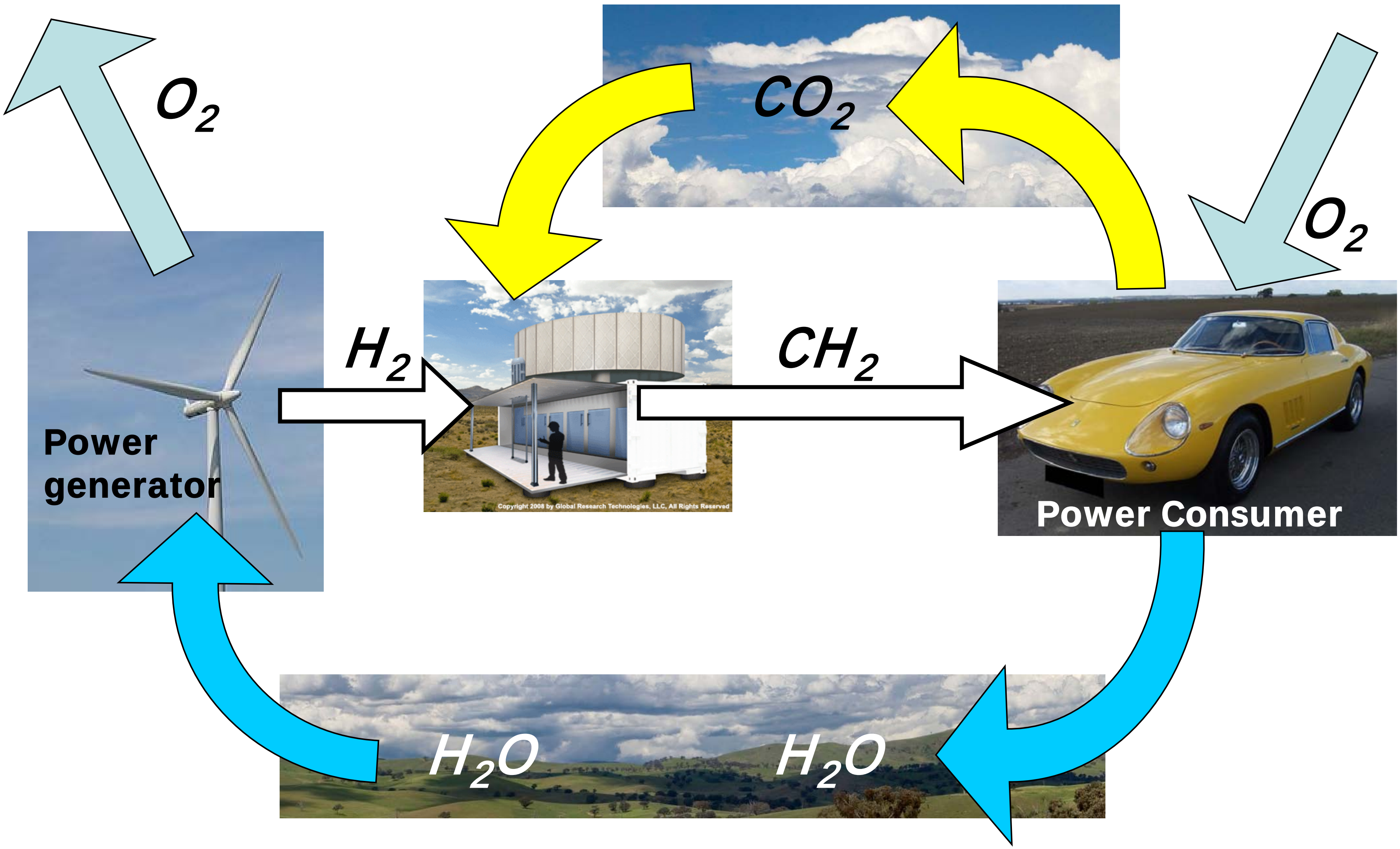
Closed Cycle - Synthetic Fuels



Separate Sources from Sinks

- *Air Extraction can compensate for CO_2 emissions anywhere*

- Art courtesy Stonehaven CCS, Montreal

After Initial Work at
Los Alamos and Columbia

GRT is to demonstrate air capture in Tucson

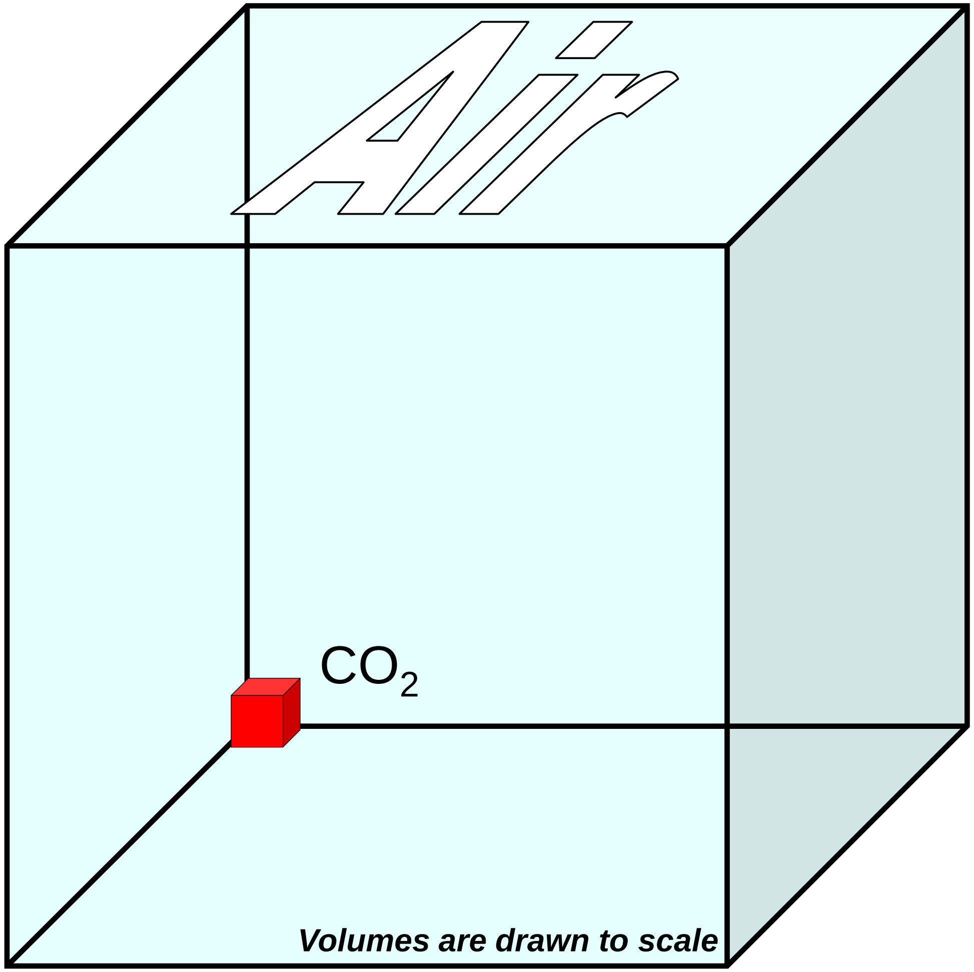
Allen Wright
Gary Comer

Deliver proof of principle

☑

KSL joined the company

CO_2 Capture from Air



1 m^3 of Air

40 moles of gas, 1.16 kg

wind speed 6 m/s

$$\frac{mv^2}{2} = 20\,\mathrm{J}$$

0.015 moles of CO_2

produced by 10,000 J of gasoline

Wind energy – Air capture

Wikipedia picture

artist's rendering

Wind energy
~20 J/m³

CO_2 combustion equivalent in air

10,000 J/m³

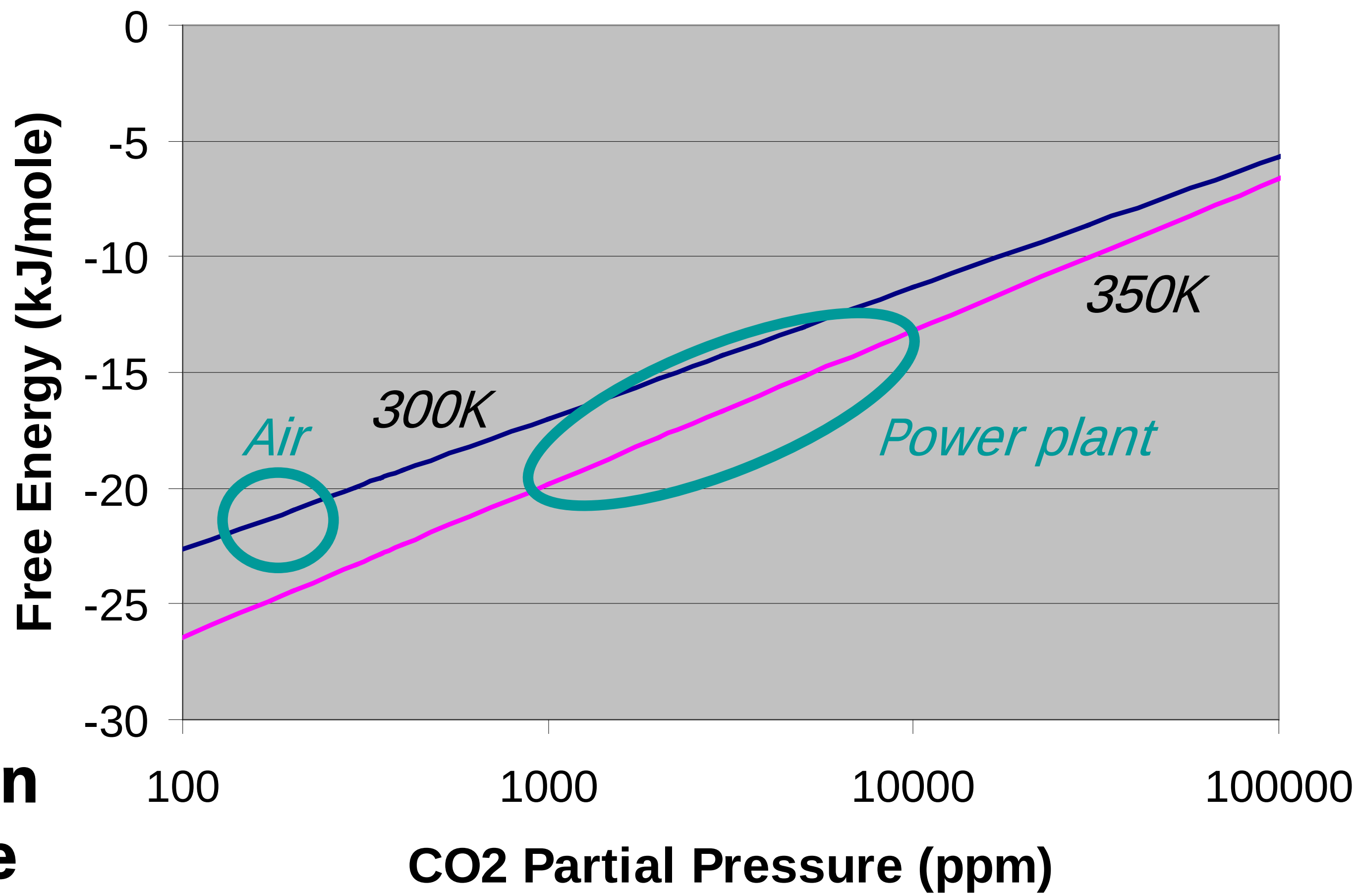
Passive contacting of the air is inexpensive

Air collector reduces net CO_2 emissions much more than equally sized windmill

Sorbent Strength

depends logarithmically on CO_2 concentration at collector exit

$$\Delta G = RT \log P$$



Sorbent regeneration is expensive

Flue Gas Scrubbing – Air Capture

artist's rendering

Dominant costs are similar for air capture and flue gas scrubbing

Sorbent regeneration slightly more difficult for air capture than for flue gas scrubbers

Anionic Exchange Resins

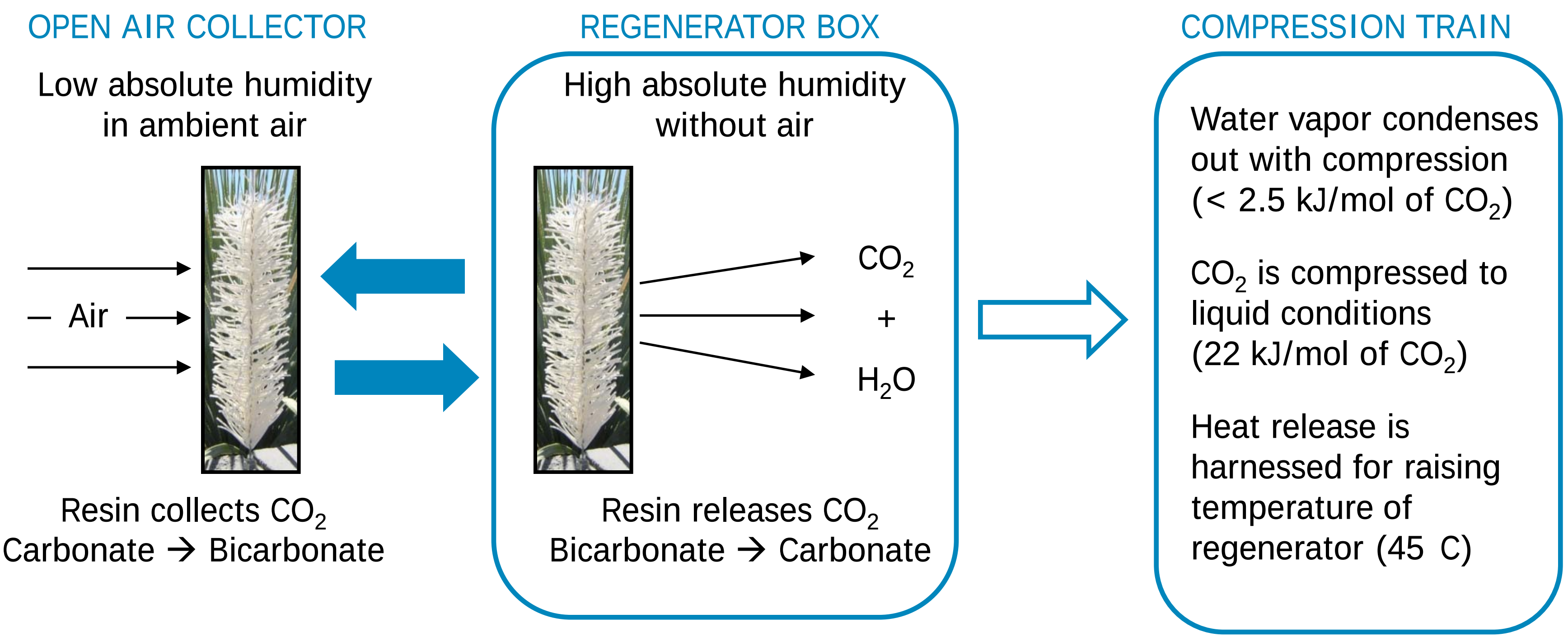
Solid carbonate "solution"
Quaternary amines form strong-base resin

- Positive ions fixed to polymer matrix
  - Negative ions are free to move
  - Negative ions are hydroxides, OH^-
- Dry resin loads up to bicarbonate
  - $OH^- + CO_2 \rightarrow HCO_3^-$ (hydroxide → bicarbonate)
- Wet resin releases CO_2 to carbonate
  - $2HCO_3^- \rightarrow CO_3^{--} + CO_2 + H_2O$

Moisture driven CO_2 swing

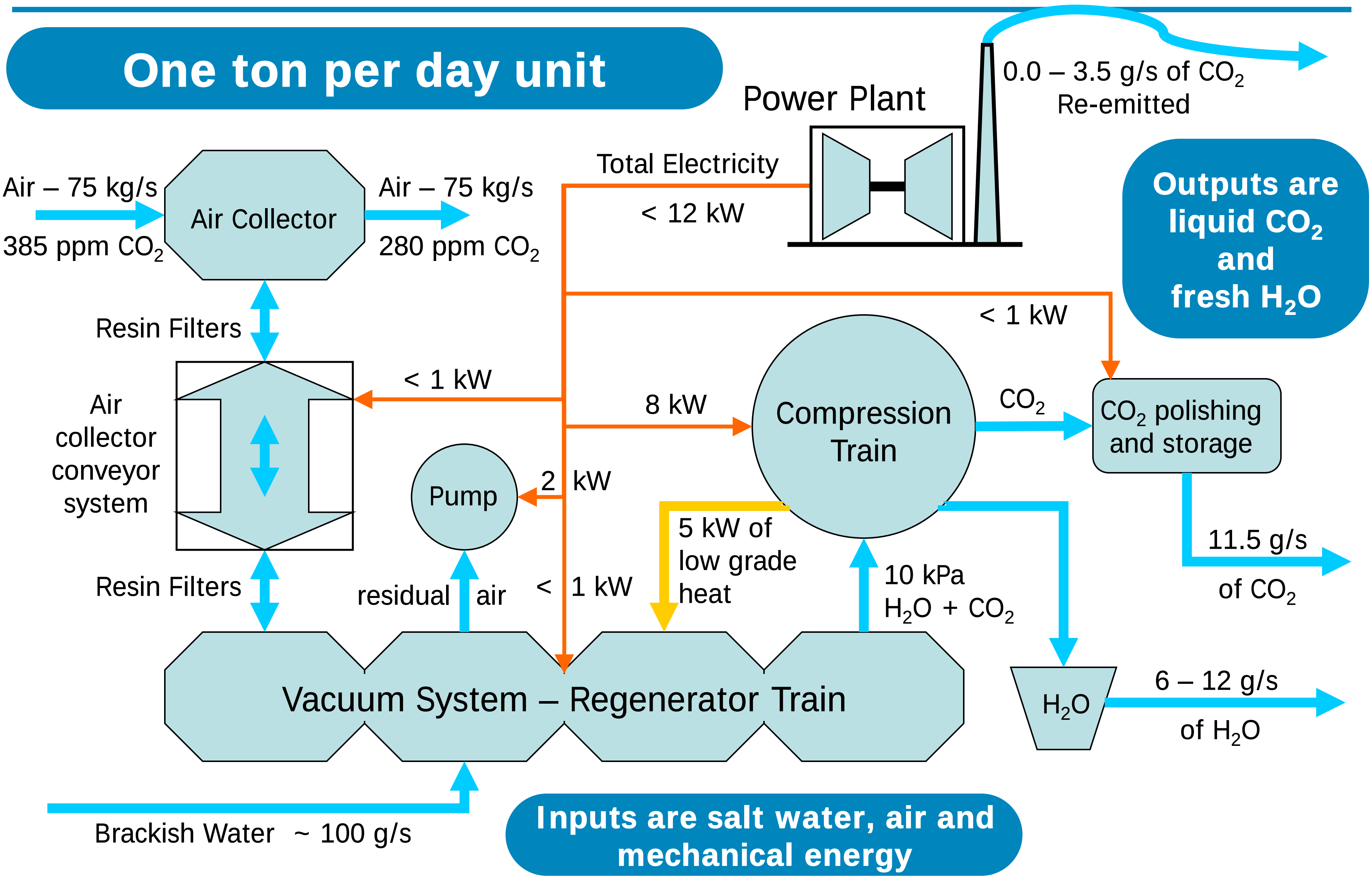
Novel Regenerator Chemistry

Moisture Swing Absorption



- Moisture swing consumes water and electric power
  - 50 kJ/mol of CO_2
  - 10 liter of saline water per kg of CO_2

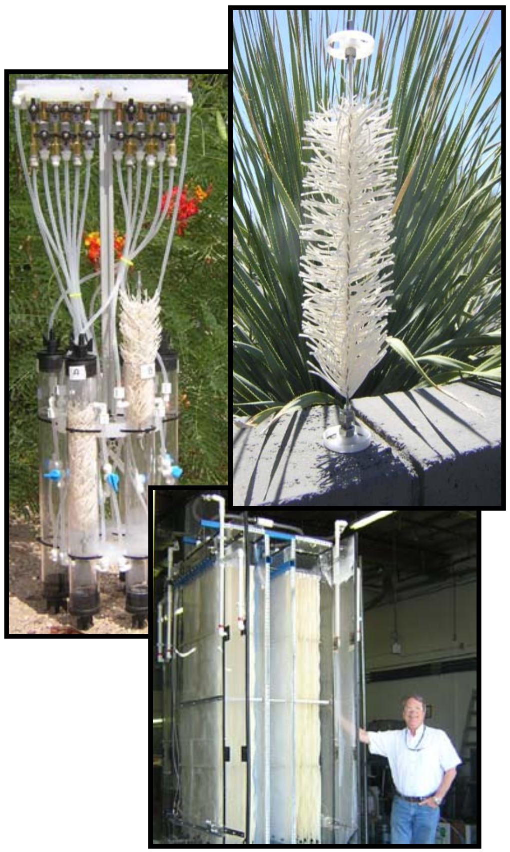
Air Capture Material and Energy Flow



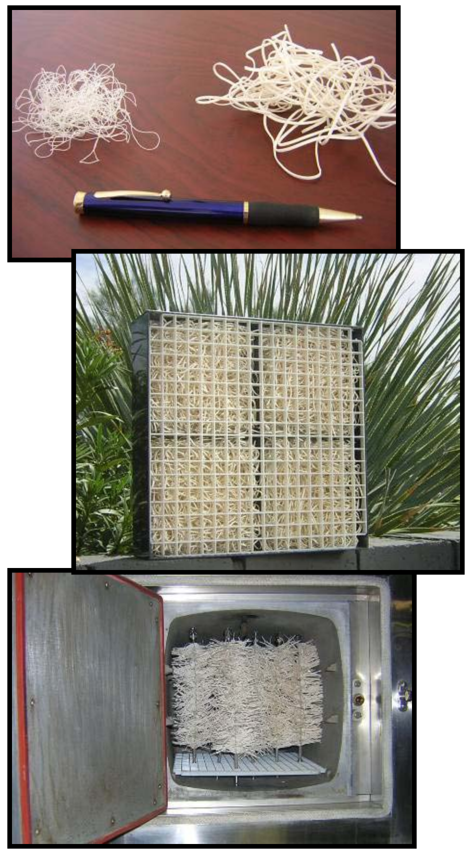
Collecting CO_2 with Synthetic Trees

From Technology Validation to Products

Prototypes of Capture Modules

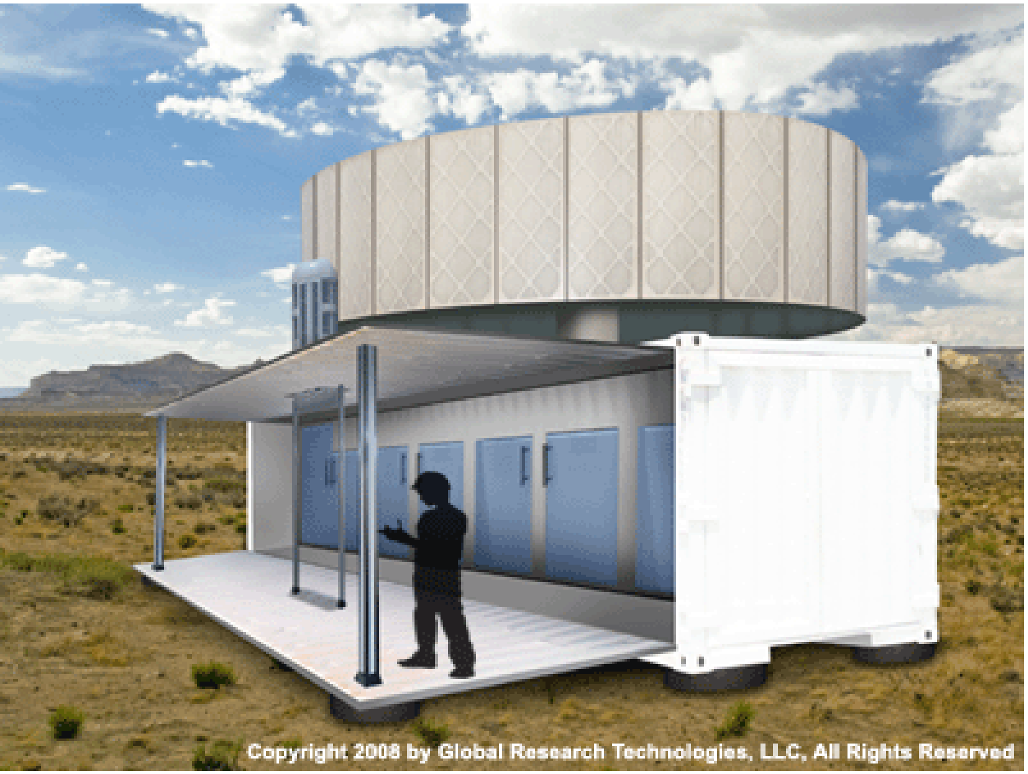


Advancing the Resin Technology



Mass-Manufactured Air Capture Units

Setting the scale for 1 ton/day



- 2   30 panels
  - 2.5m   1m   0.3m
- 2   2500 kg of resin
  - 10,000m^2 of surface
- 6   Chambers
  - 4m^3 each
- One Container
  - 86m^3
  - can hold all panels

Assembly line based automation

Air Capture Economics

Move to mass manufacturing
Initial cost are high – but less than local market prices

Cost Items	Cost Impacts
Raw materials	Low
Energy	Low
Manufacturing	High
Maintenance	High
CO_2 Storage	Initially None

Launch: Single Mobile Units
No innovation, catalog prices for parts

- Unit cost: ~$200k / unit
- Operating Costs*: ~$125 / ton of CO_2
- CO_2 Delivery Price: ~$250 / ton of CO_2
- CO_2 Output: ~ 1 ton / day / unit
- Units can be mass-manufactured
- Delivered in standard shipping containers

Maturity: Air Capture Parks
Learning and streamlining
Improvements in resins

- Unit cost: < $20k / unit
- Operating Costs*: < $20 / ton of CO_2
- CO_2 Delivery Price: ~ $30 / ton of CO_2
- CO_2 Output: ~ 1-3 tons / day / unit
- Range of collector styles, recovery systems

* Operating costs include all electrical, water, labor and material inputs

Scaling Up

- 10 million units
  - 1 million per year
  - 3.6 Gt per year
- 100 million units
  - 10 million per year
  - 36 Gt CO_2 per year
- Annual car and light truck production
  - 70 million per year
- 100 million bbl/day
  - 8 Gt CO_2/year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